Faster simulated track reconstruction in the ATLAS Fast Chain

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The ATLAS Inner Detector

- Track reconstruction in ATLAS happens in the ID
- Multiple layers of silicon detectors, plus transition radiation tracker
  - 2 T solenoidal magnetic field
Pile-Up at the LHC

• Every bunch crossing at the LHC comes with many pp collisions

• Only a few will be high-energy collisions
  - These will have the hard-scatter (HS) processes that we are interested in

• That leaves dozens of low-energy pile-up (PU) collisions
  - And their many associated tracks
Pile-Up at the LHC

- So far in Run-3, pile-up peaks at ~50 vertices per crossing
  - Significant increase from Run-2
  - For HL-LHC, 200 expected

- Problem for simulating events
  - Simulated events must include pile-up vertices
  - Don’t want to spend most simulation time on pile-up vertices

- Solution: simulate pileup separately and reuse it
Simulation With Pile-Up

- Pile-up events can be simulated ahead of time and re-used
- Simplest option: merge with the hard-scatter event after simulation
Simulation With Pile-Up

- Pile-up events can be simulated ahead of time and re-used

- Current approach: digitize the pile-up and then merge with the HS event during digitization
  - Comput Softw Big Sci 6, 3 (2022)
Simulation With Pile-Up

- Pile-up events can be simulated ahead of time and re-used
- Possible new approach: reconstruct both PU and HS separately and combine
  - Only for Inner Detector (ID) tracking
- Good approximation as long as HS tracks don’t pick up PU hits
Track Validation

- Good agreement in main track parameters
- Track overlay reconstructs slightly fewer tracks at higher $\eta$ and lower $p_T$
  - Fewer fakes when HS and PU hits are not allowed to mix
B-jet Validation

- Part of reconstruction most directly affected by ID tracking changes
- Validation performed using $t\bar{t}$bar samples
- No significant disagreement between MC overlay and track overlay
Track-in-Jet Validation

- As expected, more significant differences seen in HS tracks in high-\(p_T\) jets
  - Higher-\(p_T\) jets are more collimated and so have higher hit densities
  - More likely for PU to effect HS track reconstruction
Track-in-Jet Validation

- Difference depends on track location within jets
- In the core of high-$p_T$ jets, track overlay is too efficient
  - Hit density is high enough that reducing it has an observable effect
Overlay Choice

- Track overlay may not be suitable for all events

- Construct a metric based on truth information
- Assign events based on the value of the metric

- Probabilistic assignment of events
  - To ensure a smooth transition between regimes

HS ID Hits
HS+PU ID Hits
Truth
Other
Overlay Choice

- Track overlay may not be suitable for all events
- Decide event-by-event which events to use it for
  - Train an NN based on truth information
Track overlay may not be suitable for all events.

Decide event-by-event which events to use it for:
- Train an NN based on truth information
- Assign events based on the NN output
Overlay Choice

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- Probabilistic assignment of events
  - To ensure a smooth transition between regimes
More than half of event reconstruction time is spent on ID tracking
- 60% at $\mu=50$

Track overlay can reduce this by a significant fraction
Computing Challenges for HL-LHC

- HL-LHC will impose considerable demands on CPU and disk usage
- Track overlay is one tool for overcoming these challenges
## CPU Reduction for HL-LHC

- Fast tracking can already achieve considerable reductions
- Track Overlay can remove most of the remaining CPU from tracking
  - Further optimization of muon and calo reco needed to gain a substantial additional speed-up

<table>
<thead>
<tr>
<th>$\langle \mu \rangle$</th>
<th>primary tracking</th>
<th>unconventional signatures</th>
<th>calorimeter, muon spectr.</th>
<th>combined recon.</th>
<th>monitoring</th>
<th>total recon.</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>124 (35)</td>
<td>- (25)</td>
<td>157 (85)</td>
<td>51 (35)</td>
<td>70 (35)</td>
<td>402 (215)</td>
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<tr>
<td>200</td>
<td>214 (50)</td>
<td>- (30)</td>
<td>176 (95)</td>
<td>94 (70)</td>
<td>100 (50)</td>
<td>584 (295)</td>
</tr>
</tbody>
</table>
Disk-use Reduction for HL-LHC

- Derivation has to be run several times a year
- Reconstruction speed-up could mean also running reconstruction at that time
- Then no need to save MC AOD
  - Projected 28% disk savings (including data)
  - Also significant saving in tape storage
Summary and Outlook

• Reconstructing ID tracks from pile-up ahead of time can speed up simulation
  - One of many necessary improvements to reconstruction
  - Important given that ID tracking takes up the largest fraction of reconstruction time
  - Combined with additional CPU from HPCs or cloud computing, could reduce disk space usage

• Track overlay method now implemented in ATLAS reconstruction

• Good agreement with current method for adding pile-up to events

• Working on implementation of filter to decide which method to use to reconstruct events
Backup
Implementation

• New setup that runs only ID tracking on simulated pileup file
  - Same tools and parameters as standard reconstruction
  - Generates the same tracking collections
  - Writes out tracks and ID hit clusters

• Pileup tracks and clusters are merged into the final track and cluster collections after HS tracking is run
  - Subsequent reco steps (e.g. muon reco) see the expected full track collections

• Only ID tracking is affected, all other steps in reconstruction proceed as normal
Track Validation

- Validation performed in dijet events

- Track overlay tracks generally have a better $\chi^2/\text{N}_{\text{DOF}}$
  - Likely due to fewer cases in which the wrong hits are associated to tracks
• Good agreement in track parameters also observed for low-$p_T$ dijet events